Drag Reduction System (DRS) Design

ME 195A | Section 01: Senior Project [Group 4]

San José State
UNIVERSITY
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Final Project Report

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Executive Summary

The Drag Reduction System (DRS) is a commonly adapted design on motor racing vehicles that aims to reduce the drag force while running down a straight racing track for an increased top speed and overtaking. It is a driver-adjustable design capable of changing the form of the vehicle's spoiler to limit or promote air flowing through the spoiler. This project recreates and implements the typical design of the DRS on the Spartan Racing (Formula SAE) student race car. The project incorporates the three major disciplines of Mechatronics Engineering, which are, Mechanical Engineering, Electrical Engineering, and Software Engineering.

The team managed to implement a 6-bar Mechanical linkage system for the design of the DRS. A spring returning mechanism was also introduced on this project as a supplement to the actuator's returning mechanism. From the decision matrix, the team was able to determine the efficiency and feasibility of different models of actuators and select the most appropriate actuator for the DRS. The chosen actuator for this project is the BIMBA 022-DXP-Series Pneumatic Piston. A variety of sensors available on the Formula SAE race car will also be implemented on the Drag Reduction System's design, including but not limited to, the throttle position sensor, the steering wheel angle sensor, the brake pressure sensor, an accelerometer, and a gyroscope. The team utilized the sensor data from the Electronic Control Unit (ECU) to calibrate the sensors for better actuation of the DRS. The final design prototype of the DRS was documented to be manufactured in the upcoming semester.

Acknowledgment

The DRS team would like to acknowledge the effort and guidance of the Aerodynamics and Vehicle Dynamics team from *Spartan Racing*. The DRS team is grateful to be collaborating and sharing the project with the Spartan Racing team. The DRS team would also acknowledge the help of *George Henesian*, the Sales Manager Representative from SMC Corporation of America, for sponsoring a portion of the project. Last but not least, the DRS team is grateful to have *Dr. Raghu Agarwal* as the team's instructor and advisor.

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Nomenclature

- San José State University (SJSU)
- Formula Society of Automotive Engineers (FSAE)
- Drag Reduction System (DRS)
- Electronic Control Unit (ECU)
- Computer-Aided Design (CAD)
- Computational Fluid Dynamics (CFD)
- Concept Design Review (CDR)
- System Design Review (SDR)
- Detailed Design Review (DDR)
- Simcenter Computational Fluid Dynamics Software (STAR-CCM+)
- Center of Pressure (CoP)
- Angle of Attack (AoA)
- Bill of Materials (BoM)
- Spartan Racing 13th Car (SR 13)
- Spartan Racing Electric 6th Car (SRE 6)
- Finite Element Analysis (FEA)

Introduction

The Spartan Racing, SJSU Formula SAE team has found that efficiency is key in the pursuit of winning a design competition. There are a few factors that lead to a reduction in the efficiency of a vehicle and the highest factor is aerodynamic drag. A dynamic drag reduction system reduces the effects of aerodynamic drag on a vehicle in real-time during the performance of the vehicle. The reason it needs to be dynamic is that given the option of having an aerodynamic package that produces downforce during each corner of the track versus having no downforce the analysis has shown to favor an aerodynamic package.

Figure 1: Drag Reduction System at 'Closed' State by Default

Where a dynamic package comes in is during the straight ways where the negative effects of drag overcome the positive ones. A dynamic package will change the configuration of the aerodynamic elements to promote high downforce during tight corners and low downforce during the straights of the track. "Less downforce means faster acceleration, and depending on the car and its setup, a higher top speed" (Partridge, 2021). In previous iterations of the system, some prototypes featured a pneumatically driven piston. The pneumatic system was controlled via a button which the driver could actuate at any time. There were a couple of issues revolving around this system including the need for driver's attention and the impulse loads driven into the aerodynamic elements. During test sessions, the drivers reported issues managing several systems while accelerating. The response to this issue is to remove the responsibility from the driver and base the state of the drag reduction system on the state of various sensors.

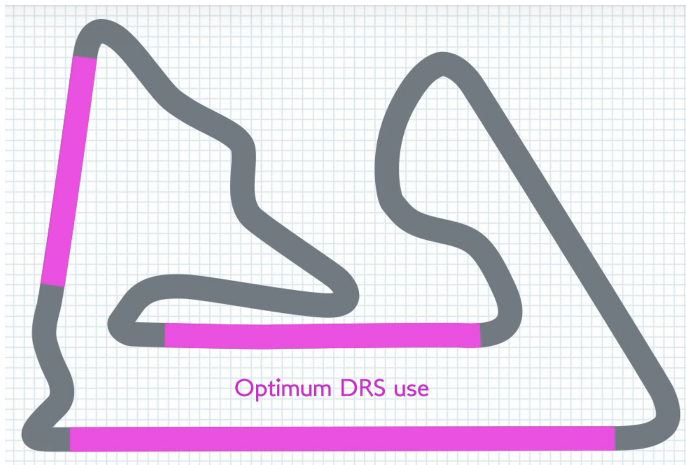

Figure 2: Race Track Map Example showing the Optimum 'DRS Zone' on Straight Paths

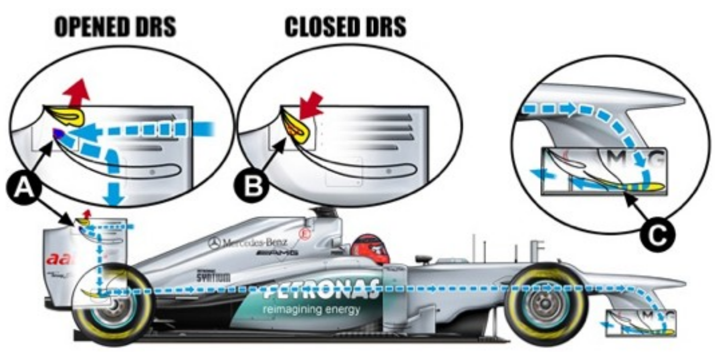

Figure 3: Typical DRS Configuration on a Formula Race Car Vehicle

The Drag Reduction System is commonly used in the real world and it's implemented on Formula 1 cars. Its main purpose is to provide as much downforce as possible. For reference, the DRS could increase vehicle performance by 5 - 7 km/h (PresticeBDT, 2021). Alternatively, it can be used to overtake an opponent in a straight line moment during the race giving the advantage to pass the cars in front of them. What sets the team's design different from a typical DRS system is the set of driver control options/states that the team is implementing on this project. In the first state, drivers are given full control of the DRS system where they will be able to open and close the flaps at any time they desire. In the second state, drivers have full control unless safety becomes an issue and that's where the DRS will override to close or open the flaps based on the feedback it gets from the sensors. The third state will be fully automatic where the ECU will have full control of whether to activate the DRS or close the DRS. The factors affecting the state of the DRS system, in this case, are the steering angle, speed, braking pressure, and throttle position. Having these states can let the drivers choose which state they are more comfortable with during competitions.

Analytical Background

Actuator Analysis

While there are many ways to energize the DRS system on the formula SAE car, the team narrowed it down to pneumatic or stepper motors. With condensed research on both pneumatic and stepper motors, it was determined that the pneumatic system is the best actuation method. However, a comparison analysis was run between the actuating method and the best choice was selected as there are rules, requirements, and specs to be considered when choosing the best fit for actuating the DRS system. While looking closely at stepper motors and pneumatics the team thought about how the actuations will benefit the team and uphold the SAE standards.

Stepper motors are known to be notoriously expensive and heavy and would need a whole new linkage design and a new ECU integration thus, leading to making it a bit more difficult to implement on the Formula SAE car. However, Pneumatic was the choice that made more sense considering the goals and requirements that the team is trying to achieve. The DRS system will be implemented on both electrical & combustion cars thus, the team wanted to avoid a heavy voltage draw to make it work in both cars so the team wouldn't have to design two different actuation methods. The pneumatic system is a simple actuating method where its components are an air tank, lines, valve, and a piston; where the air pressure can be controlled and released at a short time allowing the DRS to be activated and deactivated within 80 milliseconds per actuation. A pneumatic system would allow the team the option to implement a return spring mechanism in case things were to go wrong on the track. The pneumatic system is a simple actuating method that fits the team’s goals and requirements to achieve great results and wouldn't be more than 800 g of extra weight added to the car.

Figure 4: The BIMBA 022-DXP Pneumatic Piston

Piston Analysis

Datasheets, CAD models, and primary sources were used to determine the key features of prospective pneumatic pistons to use. System integration and driving characteristics were considered when doing side-by-side comparisons. Key feature data was recorded in a spreadsheet for efficient analysis, Table XX in the appendix. Critical features like weight were confirmed with brand representatives when uncertainty surrounded the specifications. An estimate of the force output by the selected Bimba 022-DXPB double-acting piston was found with force and pressure relationships. The following Equation 1 was used, where F is force, P is pressure and A is the effective area of the cylinder.

$$F = P \times A \qquad (1)$$

Max force was calculated to be ~22lbf. Figure 16 in the appendix demonstrates how the effective area and force were calculated using Equation 1.

Actuation Instances Analysis

Previous competition data from Michigan and Crow's airstrip was analyzed with MoTeC software, i2Pro. Conditional functions paired with filters and delay functions enhanced the data so DRS actuation simulation could be run. Parameters for the system were tuned so that unfavorable operation was avoided. This led the team to determine what sensors could be considered reliable and the outcome was that steering rate should not be used as a parameter at this time. Figure 17, Figure 18, Figure 19, and Figure 20 in the appendix show the process flow for how parameters were analyzed by the software. Figure 5 shows the results of running the simulation with a satisfactory outcome of DRS actuation instances on straight sections and mild, long turns. Before the satisfactory simulation was achieved, data for a worst-case scenario was recorded, a simulation where DRS opened too frequently and at the incorrect times. With this data from the Michigan Endurance event, the longest race, the maximum time that the DRS system would actuate for was about 134 seconds.

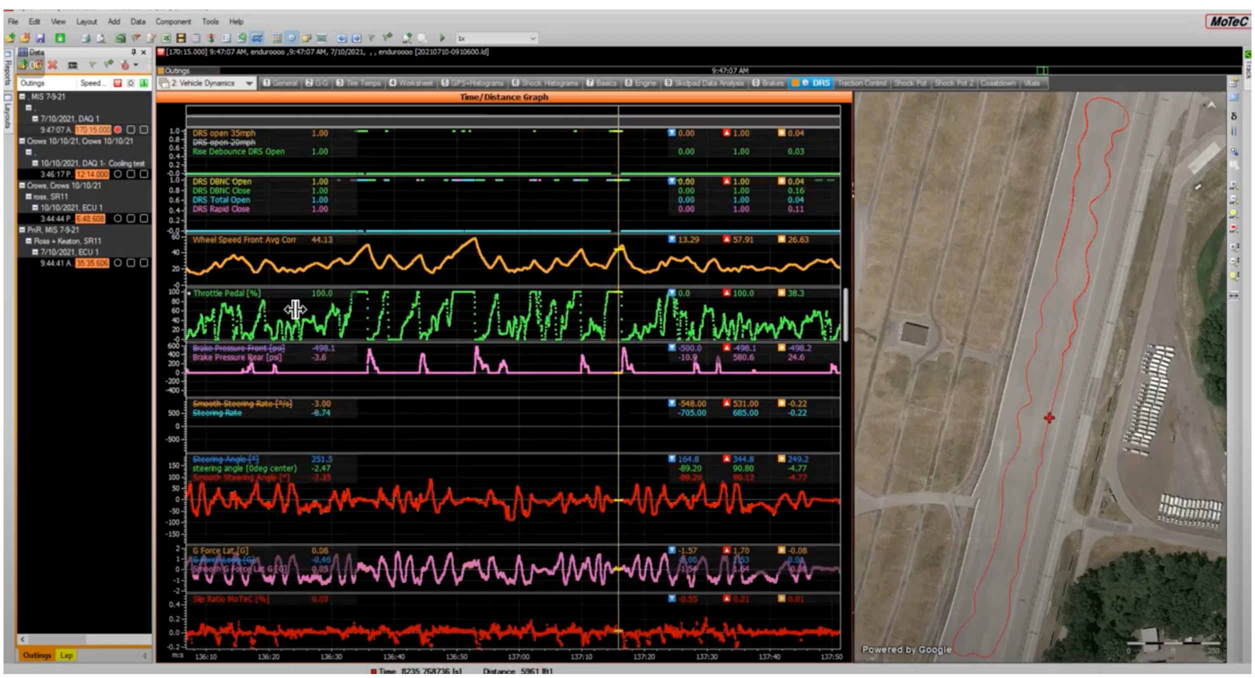

Figure 5: The favorable operation of DRS Total Open, cyan line, 2nd row

Spring Return Mechanism Analysis

The actuation mechanism of the Drag Reduction System features a BIMBA 022-DXP Pneumatic Piston. Traditionally, there are two types of pneumatic pistons, a single-acting piston, and a double-acting piston. A double-acting piston is capable of extending and retracting with the pumping of air on both sides of the piston. A single-acting piston, on the other hand, requires a manual spring to retract the air piston. The BIMBA 022-DXP Pneumatic Piston is a double-acting piston, which means there is no built-in spring on the air piston itself. Consequently, the air piston tends to shift or vibrate when the car is running. To solve that issue, the DRS team designed a spring return mechanism on the air piston. A spring capable of operating under vibrations and heat was chosen. The DRS team calculated the minimum spring constant required by using the Hooke's Law formula, where F represents force, k represents the spring constant, and x represents the spring displacement:

$$F = kx \tag{2}$$

From the datasheet of the BIMBA 022-DXP Pneumatic Piston, it can be estimated that 25% of the maximum amount of force exerted by the piston is 5.5 lbf. The total distance traveled by the spring was calculated to be 2.25 in, as shown in Figure 21 in the Appendix. Therefore, the spring constant, k, was calculated to be 2.44 lbf/in. The DRS team was able to find a spring with a spring constant rating of 2.6 lbf/in and an extended length of 5.98 in. With the addition of the spring return mechanism on the pneumatic piston, the air piston will be able to retract in the case of valve failure. Therefore, the spring return system acts as a fail-safe for the Drag Reduction System.

Computational Fluid Dynamics Data Analysis

With the help of the Aerodynamics team from Spartan Racing, SJSU Formula SAE, the Drag Reduction System team was able to collect Computational Fluid Dynamics data to decide the actuation options available on the vehicle. The available options are actuating the upper two spoiler flaps, the lower two spoiler flaps, or all 3 spoiler flaps. The purpose of this analysis is to study the effect of the spoiler flap actuation on the car's overall performance. The aerodynamics team was able to simulate the car at different speeds and actuation options using Simcenter STAR-CCM+ CFD software. From the table of results (shown in Appendix), the DRS team has determined that the best option for the DRS is to actuate the lower two flaps. The CFD data on the table below shows that the amount of drag produced on the car is relatively lower in the cases of the upper 2 flaps opened and all flaps opened. However, the Center of Pressure (CoP) rating shows that the car has the lowest shift in the center of pressure for the case of the lower 2 flaps opened. Taking into account the center of pressure of the car, the team has decided to design the DRS by actuating only the lower 2 flaps on the car's spoiler.

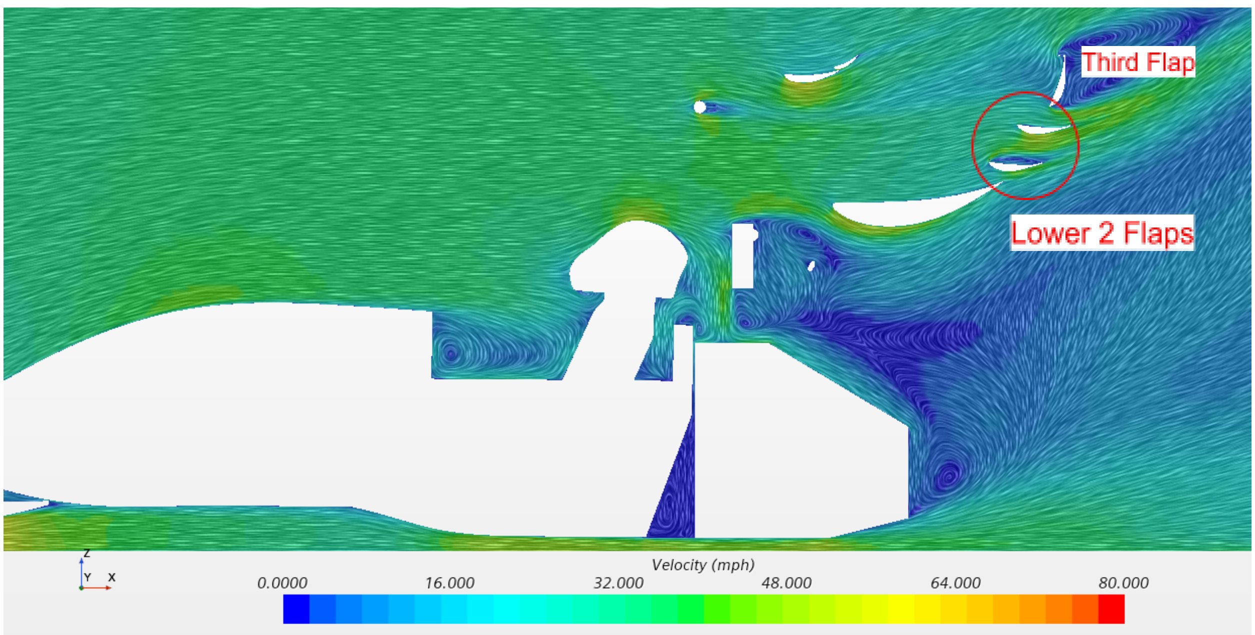

Figure 6: Computational Fluid Dynamics Analysis for Lower 2 Flaps

4-Bar Linkage Analysis

The main mechanism of the DRS system is a pneumatic piston actuated 4 bar linkage. The mechanism is constrained in two-dimensional movement by the ground link which is the rear wing structure. The purpose of this mechanism is to rotate and position the middle two flaps on the rear wing assembly between the designed Angle of attack (AoA) and flat, lowest drag position.

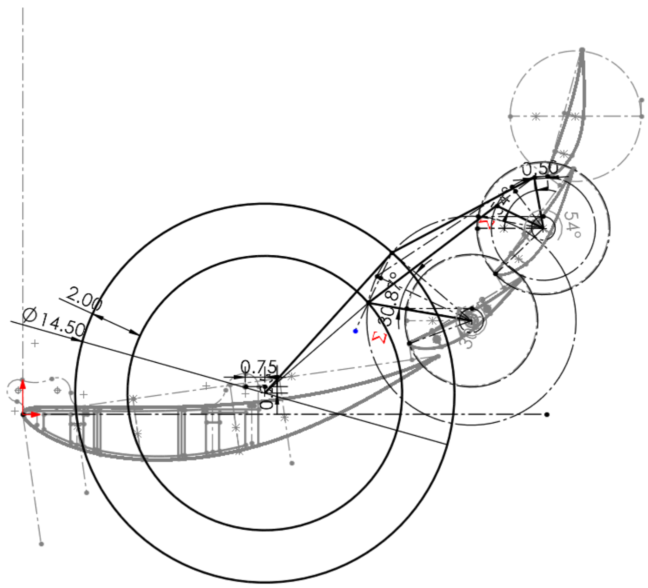

Figure 7: SolidWorks CAD of Mechanism Kinematic Sketch

The main design factors that were considered during the designing of this mechanism are packaging, component compatibility, and efficiency. In terms of packaging, the areas of focus are the proximity of the linkage nodes in relation to the other components and wing elements to prevent collision during operation; and the frontal area of different components and aero profile change of the flaps incurred on by the mounted components. Component compatibility between all the parts and other potential options of off-the-shelf components were considered in case of difficult sourcing specific components now or in the future. A major interest and potential gain from the design of the kinematic is the mechanical efficiency of the mechanism. A high mechanical efficiency would reduce the weight of most components, lessen the loads on the composite flaps, and increase the number of available actuations with the same amount of air in the air tank. The method to evaluate the mechanical efficiency of a four-bar mechanism is through the transmission angle value. A high transmission angle entails a high mechanical efficiency of the mechanism. The analytical definition of transmission angle is:

$$\tan\mu = \frac{\text{Force component tending to move the driven link}}{\text{Force component tending to apply pressure on driven link bearings}} \tag{3}$$

$$\sin\mu = \frac{\text{Force component tending to move the driven link}}{\text{Total force applied to the driven link}} \tag{4}$$

The graphical definition of transmission angle is the angle formed by the force transmitting member to the driven member. The two transmission angles in this 4 bar mechanism are 50.9 degrees and 63.8 degrees respectively shown in the figures.

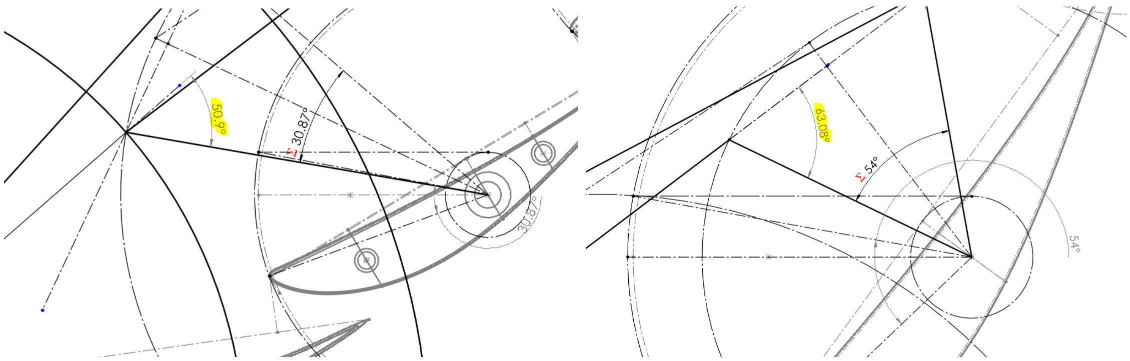

Figure 8: SolidWorks CAD Demonstration of the Transmission Angles

Prototype

Mechanical Design

A spring return mechanism is utilized on the BIMBA 022-DXP Pneumatic Piston to act as a fail-safe mechanism. In the case that the air valve stops working and the actuator is stuck in the extended position, the spring return will retract the tip of the piston back to its original position. To incorporate the returning spring on the piston, the team used a set of shaft collars with respective sizes that fit on the piston’s tip and body. A pair of sheet metal was also constructed to serve as a spacer and holder for the returning spring. A spring with a rated spring constant, k, of 2.6 lbf/in was selected for this design.

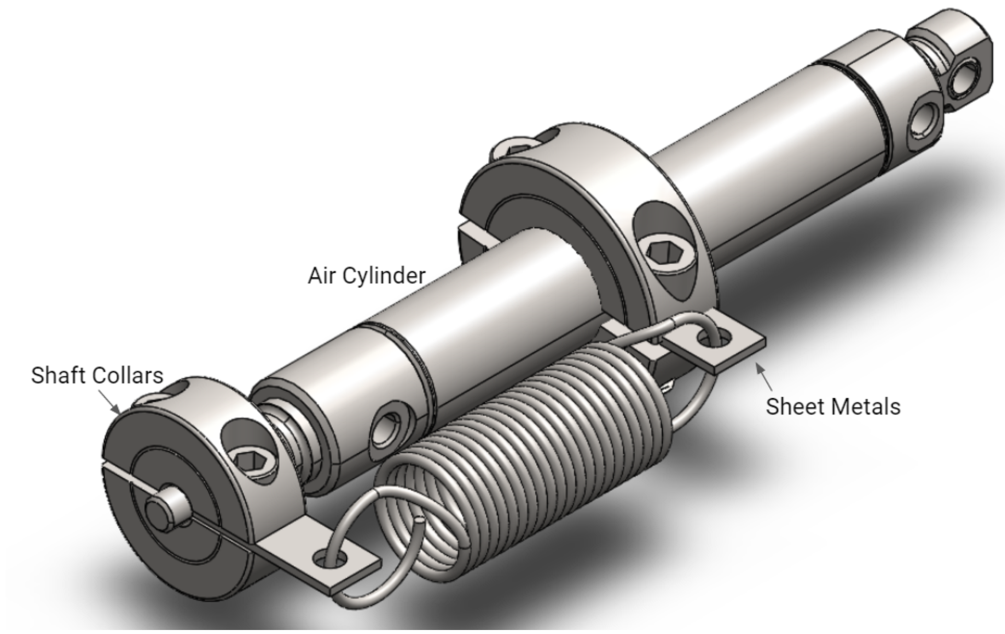

Figure 9: SolidWorks CAD Assembly of the Return Spring Mechanism Prototype

The pneumatic piston actuator requires a through-bolt mounting at the bottom. A sheet metal bracket is designed to mount the main element of the rear wing and the swan neck rear wing mounts. This sheet metal bracket offers a desirable mounting location for the pneumatic piston due to its close proximity to the main structural support of the rear wing, ease of fabrication, low cost, low weight, and stability.

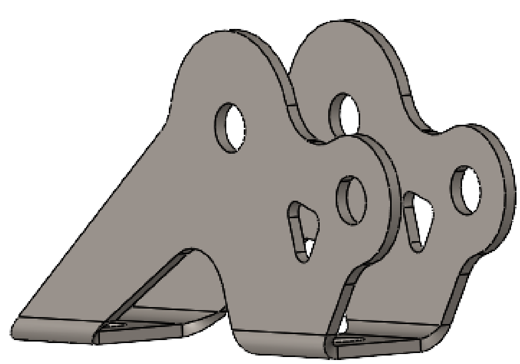

Figure 10: SolidWorks CAD of the Pneumatic Piston Mounting Bracket

This bracket is expected to withstand 25 to 30 pounds (100psi of line pressure and 9/16 inch piston diameter results in 24.85lbf of force) of force during the pneumatic piston actuators.

A finite element analysis using the Solidworks simulation package was conducted using similar real-world conditions. The stiffness of the material proved to be more than adequate and yielded a safety factor of 2.7.

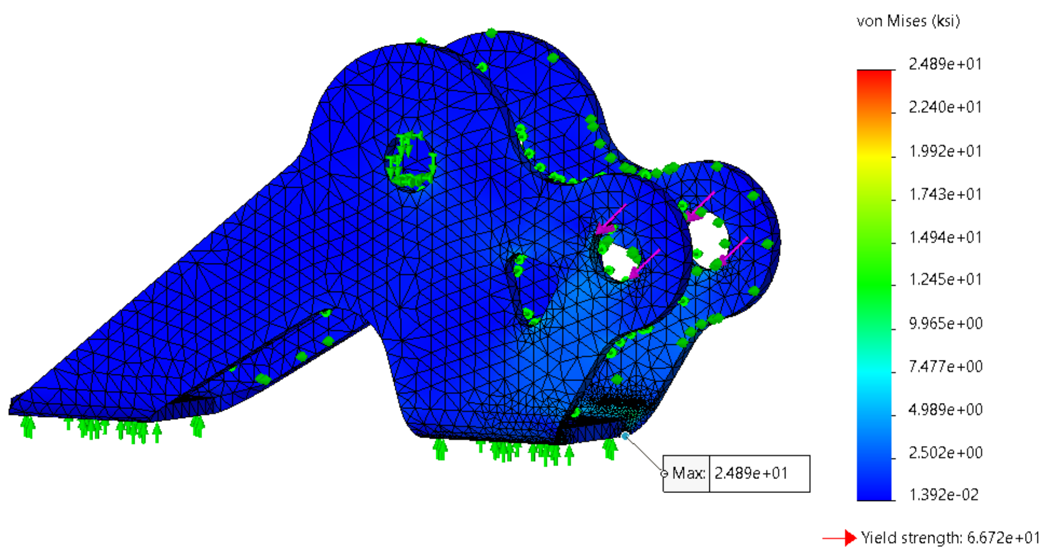

Figure 11: SolidWorks FEA Stress plot of the Pneumatic Piston Mounting Bracket

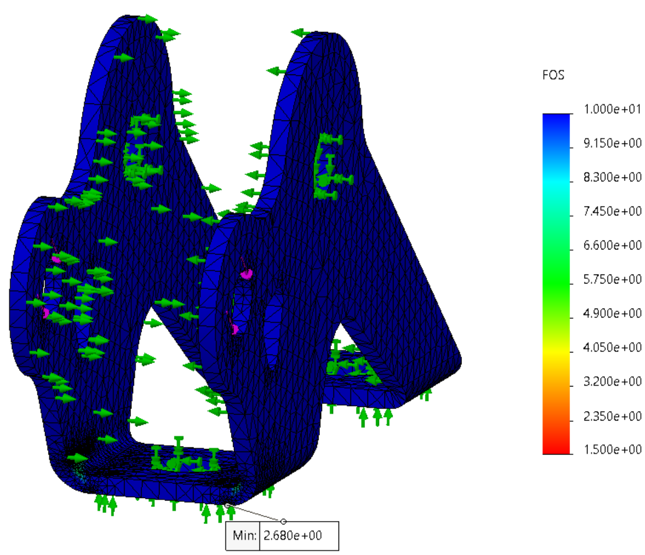

Figure 12: SolidWorks FEA Factor of Safety plot of the Pneumatic Piston Mounting Bracket

Electrical Design

The pneumatic piston will be controlled by an electronic valve, a double solenoid exhaust center valve that can operate off the 12V system. The valve was selected as it can withstand the system pressure of about 120 psi, up to 145 psi maximum, and has a low power consumption of 0.65 W. This valve made by SMC is fast-acting with a 33ms response time. Initially, a closed center valve was specified for the system but was found to be dangerous in the event of valve failure, the piston would stay pressurized and possibly in the open position. The nature of the exhaust center valve releases all pressure when solenoids are at rest and if the valve failed, the air within the piston would be able to exhaust. Exhaust center style valves do consume more air but for the minimal frequency of operation of the DRS, the difference in the air is negligible. If the system were to remain extended for hours, the closed center-expended air mass would be a more significant saving. The worst-case scenario time that was used to calculate a maximum power consumption reference was critical for the electric formula car team. With the solenoid valve consuming 0.65 W and considering the worst-case maximum operation time, approximately 0.024 Wh would be consumed over the long endurance race period. This max power consumption reference was found to be satisfactory but the DRS needs to undergo track testing to see how actuation parameters may need to be modified and how power consumption would change in response.

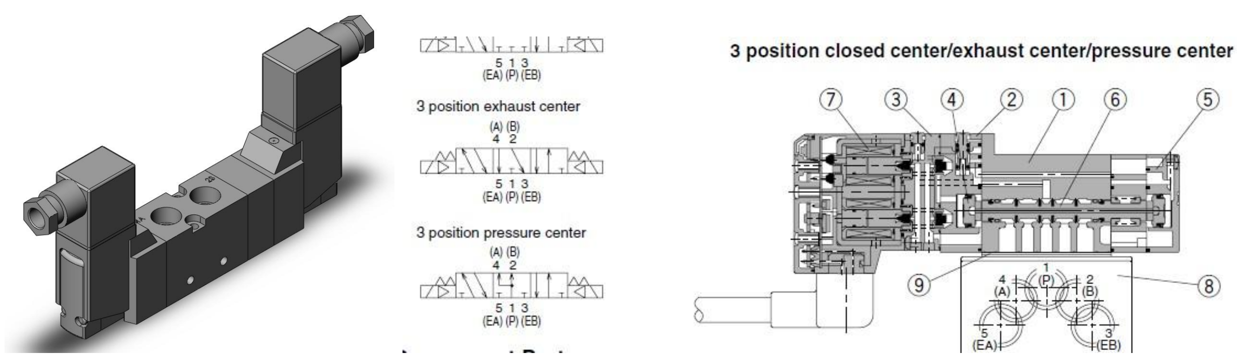

Figure 13: SMC 5 Port Solenoid Valve

Software and Controls Design

The primary objective of the Drag Reduction System project is to create a system that would actuate automatically when the appropriate conditions are met. At the same time, the DRS team would take the driver's preference into account when designing the fully-automated system. Therefore, the DRS team constructed a flowchart, shown in the Figure below, that better explains the available options for the driver to actuate the DRS. The default state of the DRS system is a deactivated state. At this state, the DRS will be in the "Closed" or "OFF" state at all times.

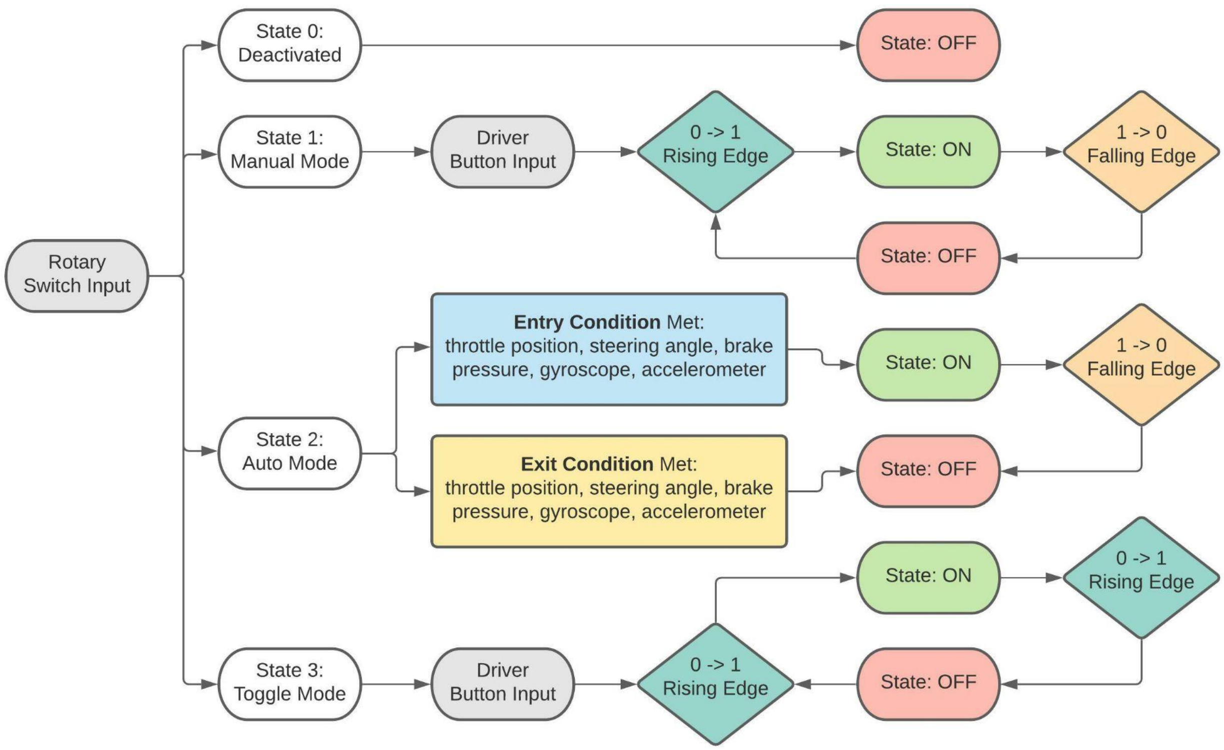

Figure 14: Drag Reduction System Design Flowchart

The first mode is called the "Manual" mode. In this mode, the driver will press the DRS input button on the vehicle, which would create a rising edge state. The presence of a rising edge would actuate the DRS to the "Open" position. When the driver stops holding on to the button, the falling edge occurs and the DRS will be closed. For the second state, also known as the "Automatic" mode, the DRS will actuate depending on the conditions and data collected from the vehicle sensors. Ideally, the system will take in data from a wide variety of sensors through the vehicle's Engine Control Unit (ECU), including but not limited to, the throttle position sensor, the steering angle sensor, the brake pressure sensor, the gyroscope, and the accelerometer. When the sensor detects that the vehicle is driving down a straight path, the program will trigger the DRS to the "Open" state. Alternatively, the opposite conditions met will trigger the DRS to the "Close" position. The last mode is called the "Toggle" or "Acceleration" mode. In this mode, the driver only needs to push the steering wheel button once to activate the DRS without having to hold on to the push button to keep the DRS open. All of the modes mentioned are designed to fit different drivers' preferences and needs.

The Engine Control Unit is the main computer that controls the vehicle. The formula student team has utilized the MoTeC M150 of the past years and will be using this controller for the DRS system. The controller utilizes two software for the user interface. The first being a tuning software M1 Tune and the second being a firmware editing software M1 Build. To simplify the two software, the M1 Tune package is like a control panel in which you are able to flip switches and adjust dials meanwhile M1 Build is like opening up the panel to add and change the switches and dials. Since the system is unique the ECU's firmware interface (M1 Build) will be used to create the dials as switches necessary to operate the DRS system. The M1 programming language is a language similar to C as is its logic. The majority of the system is object-based therefore using Figure 14 the enumeration was able to be determined in Figure 15 then a group within the object's class was defined with those referenced modes. Depending on each of the modes scripts will be written which will emulate the results from the MoTeC I2 Pro analysis shown in Figure 5.

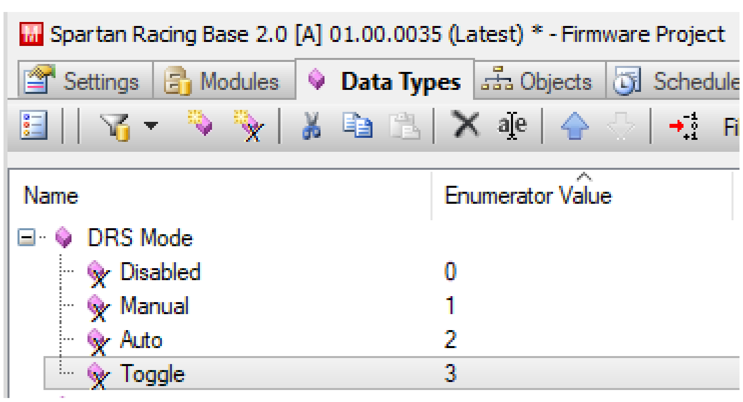

Figure 15: Drag Reduction System Mode Attributes in M1 Build

Conclusion

The main purpose of the Drag Reduction System (DRS) is to allow the driver to adjust the aerodynamics of the car leading to reducing the amount of drag that is being exerted on the car in a straight line allowing the driver to go faster. Throughout the semester the team designed the mounting bracket for the piston that will be implemented on the rear wing as well as the linkages allowing full and smooth optimization of opening and closing the flaps of the rear wing. The team decided to design a return fail mechanism where under extreme conditions mid-race that the pneumatic system fails the flaps would close by the spring that is mounted to the piston allowing it to close the flaps and not sacrifice the downforce that is needed when taking sharp corners.

While our design should work properly throughout the competition there are many improvements such as relocating the mounting of the piston for better aerodynamic flow, reconsidering servo motors, re-run CFD data on the flaps, and considering adding DRS to the front wing of the car to help with downforce and turning around sharp corners. Moving forward, the team is going to implement the design of the DRS on the Spartan Racing combustion (SR 13) and electric team's (SRE 6) vehicle with the support and the calibration of the Powertrain team, aerodynamic, and vehicle dynamics team.

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Appendix

A. General Information

Table 1: Drag Reduction System Team GANTT Chart

Specific Task	Start	End/Due	Aug 08	Sep 09	Oct 10	Nov 11	Dec 12	Jan 01	Feb 02	Mar 03	Apr 04	May 05
Research	8/25	9/1										
Reach out to Aerodynamics Team	8/29	9/1										
Project Proposal + IP Plan	9/1	9/8										
Mini Report	9/8	9/22										
Concept Design Review	9/18	9/25										
Inventory Check	9/1	9/29										
Initial Design	9/1	10/31										
Project Presentations	9/14	10/6										
	10/14	11/3										
	11/14	12/1										
CAD	9/1	10/30										
FEA/CFD	9/1	10/30										
Manufacturing (Fall)	10/1	11/30										
Testing (Fall)	11/1	12/30										
Project Report (Fall)	11/17	12/6										
Manufacturing (Spring)	1/1	3/30										
Testing (Spring)	2/1	4/30										
Validation	2/1	4/30										
Final Project Presentation (Spring)	5/1	TBD										
Vendor & Sponsorship Outreach	8/19	5/1										

Table 2: Bill of Materials (BoM)

Item #	Item Name	Source	QTY	Cost (each)
Bimba 022-DXPB	9/16" x 2" **Double Acting Piston**	TSI	1	36.30
SMC TIUB07BU-20	1/4" OD **Air Line**	SMC	1	24.00
SMC AR20-N02-YZ-B	**Pressure Regulator**	SMC	1	14.90
SMC KQ2H07-32A kq2	Bimba **Piston Fittings**	SMC	2	3.22
VF3433K-6D1-02N	3 pos, ex center VF3, rated to 145 psi, **Solenoid Valve**	SMC	2	156.75
TIL01-16	1/8 TIL line 16 meters	SMC	1	95.00
KQ2H01-35AS1	1/4 NPT to 1/8 **Line Fitting**	SMC	15	2.71
B094YJJZWV	**Air Tank**	Amazon	1	49.99
5108N6	**Spring Return**	McMaster	1	9.41
6436K53, 8386K45	**Spring Mounting** & Miscellaneous	McMaster	1	21.59
		DRS TOTAL =		**611.78**

B. Design Calculations and Analysis

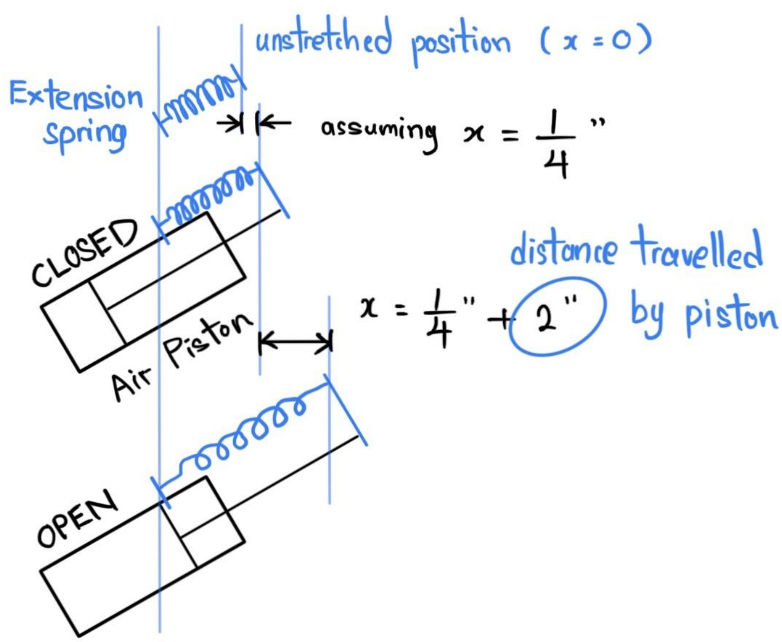

Figure 21: Calculation of the Total Distance Travelled by the Return Spring

Table 3: Computational Fluid Dynamics Data for Different Actuation Options

Conditions:	No Flaps Open	Upper 2 Flaps Open	Lower 2 Flaps Open	All 3 Flaps Open
Half Car Df (lbs)	180.54	130.88	135.56	116.29
Half RW Df (lbs)	78.57	38.13	41.75	26.78
Full Car DF (lbs)	361.08	261.76	271.12	232.58
RW DF (lbs)	157.14	76.26	83.5	53.56
Half Car Drag (lbs)	83.19	54.03	55.72	48.16
Half RW Drag (lbs)	36.06	12.63	16.19	8.96
Full Car Drag (lbs)	166.38	108.06	111.44	96.32
RW Drag (lbs)	72.12	25.26	32.38	17.92
CoP (%F)	51.9	79.8	74.77	90.2

Table 4: Piston Selection Analysis

Manufacturer	Bimba	SMC	SMC	SMC	SMC
part #	022-DXPB	NCDGBA20-2200-X142US	NCDGCA32-0200	NCDGLN20-0200-M9NW	NCDGCA20-0200
cost	36.33	72.8	56.85	123.6	46.6
max force at 100psi	22.6 lbf	40.9 lbf	107 lbf	40.9 lbf	40.9 lbf
piston stroke	2in	2in	2in	2in	2in
mass	68g	322.05g	470g	68g	210g
damping	internal rubber bump stop	internal urethane cushion	air cushion	internal urethane cushion	air cushion
air line ports threads	10-32 UNF	10-32 UNF	1/8in NPT	10-32UNF	
piston head thread	10-32	M8x1.25	M10x1.25	M8x1.25	
source	TSI	SMC	SMC	SMC	SMC
mount	rear clevis	basic style	rear clevis	axial foot style	rear clevis
position sensor	yes	yes	yes	yes	yes
bore OD	15mm	20mm	32mm	20mm	20
effective area (bore ID - piston OD)		2.64x10^-4 m^2	6.91x10^-4 m^2	2.64x10^-4 m^2	
	0.226 in^2	0.409 in^2	1.07 in^2	0.409 in^2	

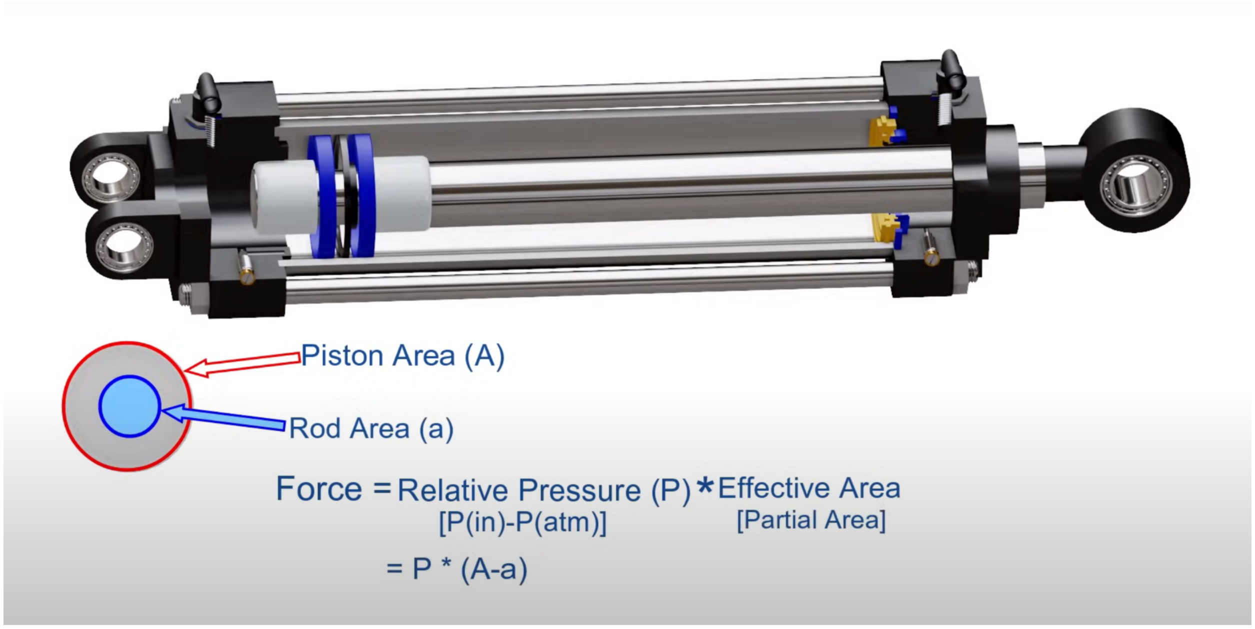

Figure 16: Piston force effective area Calculations

Table 5: Decision Matrix for Actuator Selection

actuation types	actuation time	system weight	electric power consumption	additional energy source required?	"fail safe" capable system	system cost	CG position(x,y,z) inches	Torque (lb/ft)	effect on aero	durability	use existing linkage
manual trigger, pneumatic linear	<80ms		1.5W	yes, pressurized air tank	no	187.5	67.1, -0.2, 9.6	4.6 lb/ft (initial)	7	10	yes
pneumatic, linear	<80ms	~800g	1.5W	yes, pressurized air tank	yes	277.55		4.6 lb/ft (initial)	5	8	yes
pneumatic, rotary	<80ms	~950g (220g)		yes, pressurized air tank		336.9					
servo	~100ms	75g		no	no	175.8		3.11 lb/ft	7	8	no
stepper motors	160ms	3.7 lbs (1.68 kg)		no	no	180.5	not good		7	5	no
Electric linear actuator	~500ms	3.5 lbs (1.6 kg)	108W	no	yes	150	not good		5	8	
hydraulic	~	9.0+ lbs (4.08 kg)		~	yes	250.3	~		5	8	no

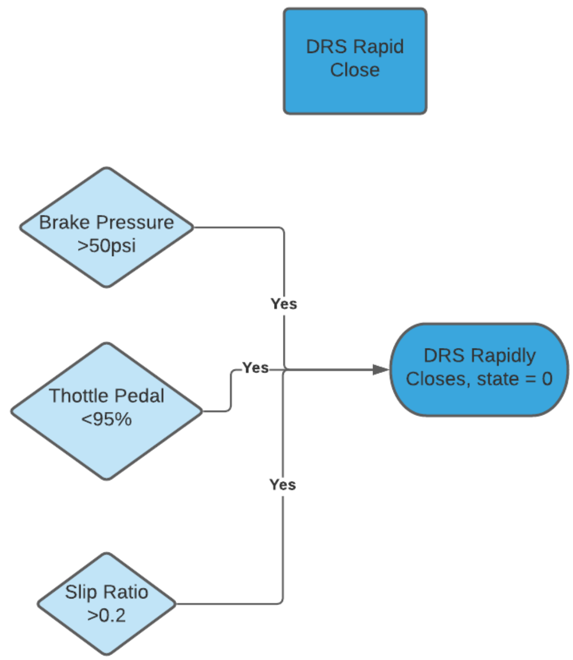

Figure 17: Flowchart Diagram of DRS Rapid Close

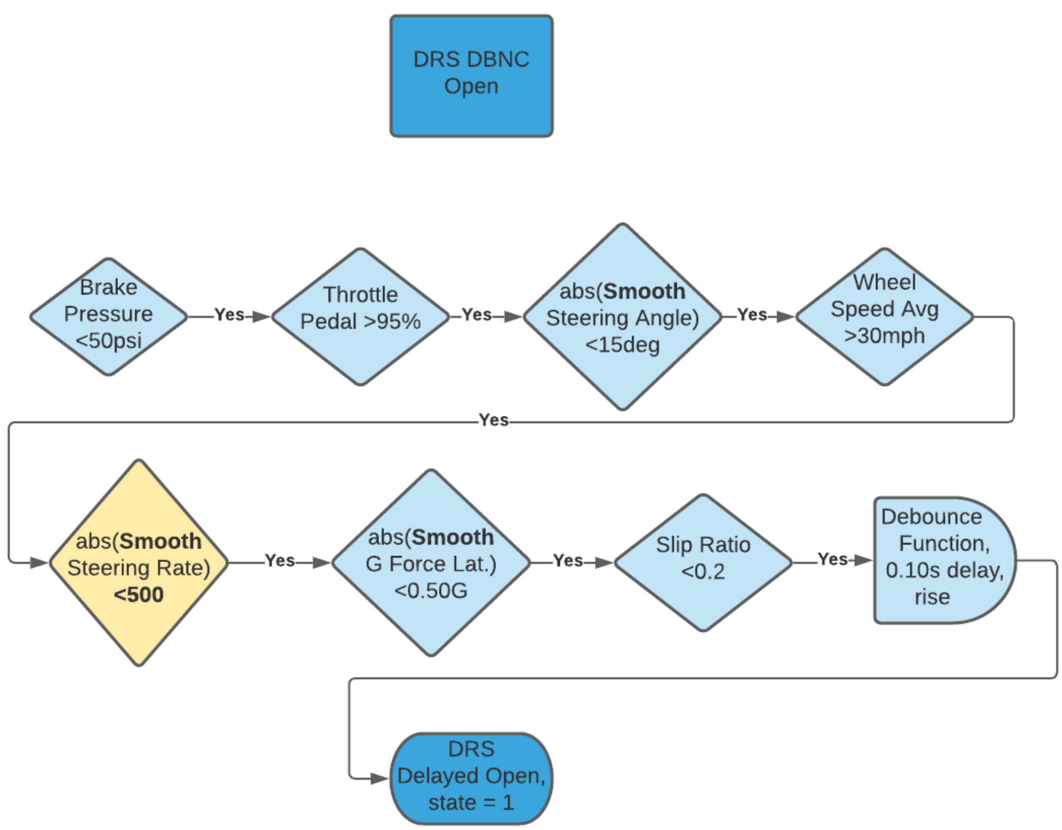

Figure 18: Flowchart Diagram of DRS DBNC Open

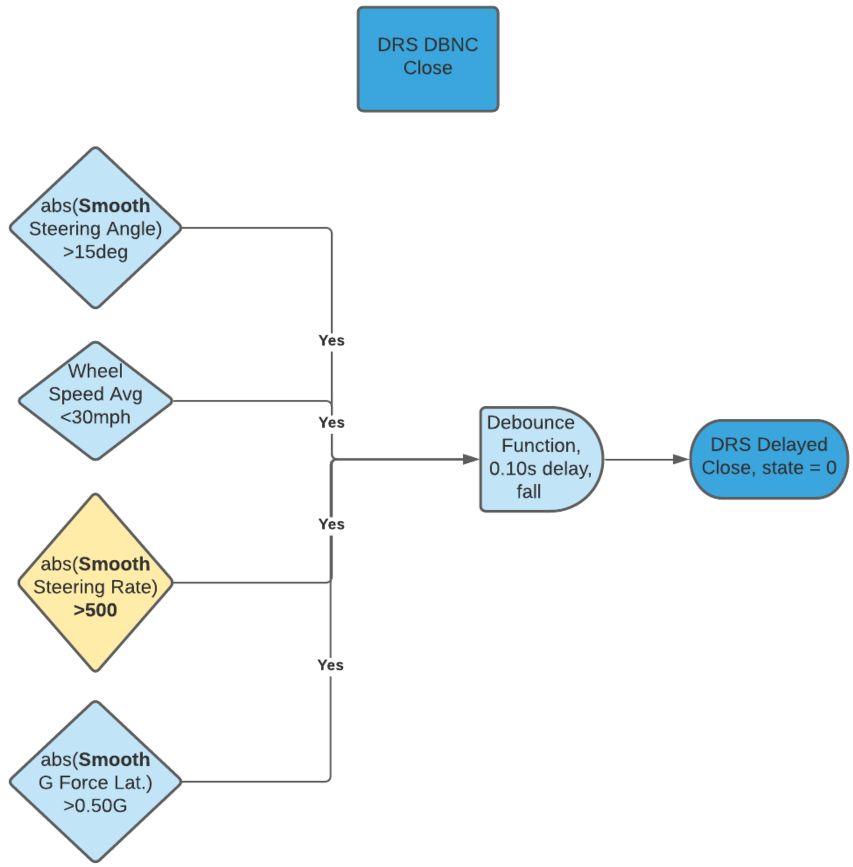

Figure 19: Flowchart Diagram of DBNC Closed

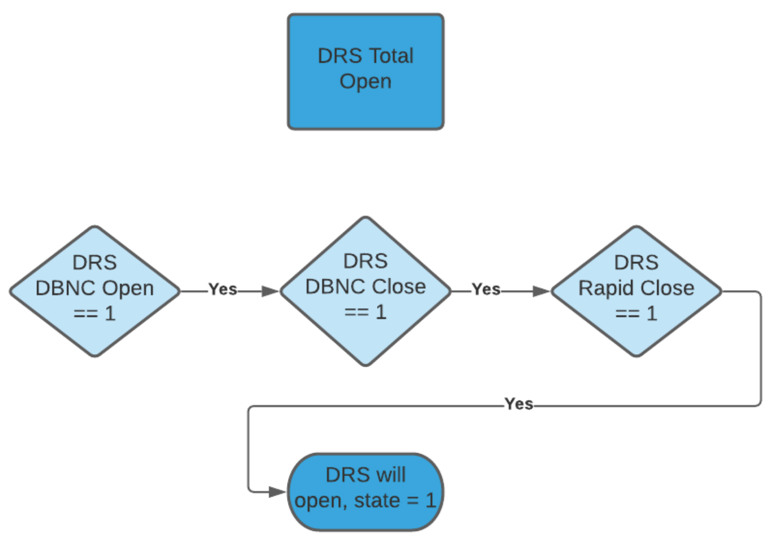

Figure 20: Flowchart Diagram of DRS Total Open

C. Design Prototypes and Models

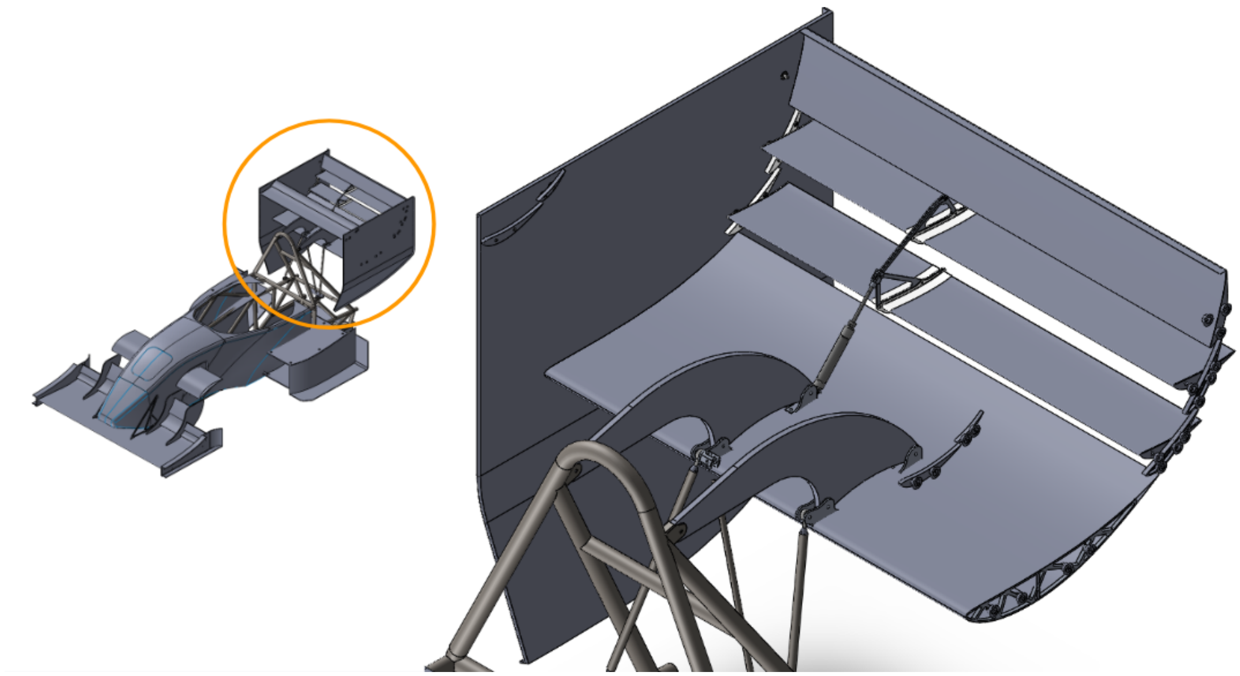

Figure 22: CAD Diagram of the complete DRS setup on the Vehicle Rear Wing (Spoiler)

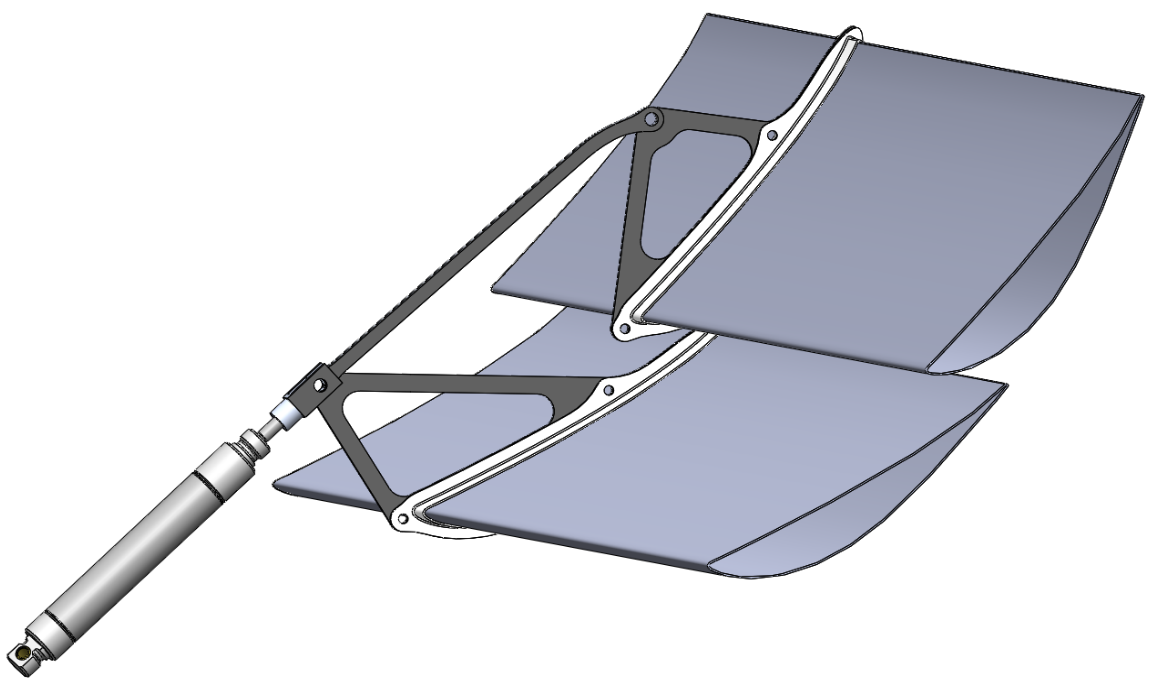

Figure 23: CAD Diagram of the complete DRS linkage setup